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UPDATE ON JAPANESE RESEARCH AND DEVELOPMENT: SUPERCONDUCTORS

Summary

Electricity and electromagnetism are such an integral part of our everyday lives that we take the technology for granted. While these two phenomena have been harnessed for many purposes, inefficient conductors, generators and storage devices have barred wider use. Breakthroughs in superconductivity promise to sweep away these barriers and launch a second electric revolution. Researchers around the globe are racing to commercialize recently discovered high-temperature superconductors hoping to capture the lead in the high-stakes competition. This report provides an overview of recent discoveries and American and Japanese efforts to exploit them. In addition, the most recent statistics on overall Japanese research and development spending are presented in an appendix.

What is a Superconductor?

Every substance either permits electricity to flow through it (a conductor) or prevents it (an insulator) in varying degrees. (For a more detailed explanation see Appendix A.) Two characteristics define a superconductor: the ability to carry an electric current without resistance, and impermeability to magnetic fields (the Meissner effect). When an electric current flows through a normal conductor, the electrons collide with the atoms of the conductor, losing energy in the form of heat. In many cases this resistance is put to good use, in electric heating elements and transistors, for example. In other situations, the energy loss is unwanted, as in power transmission lines and electric motors. A practical superconductor would greatly increase global

energy efficiency as well as lead to new products and machines. For example, it would make a high-speed magnetic levitation train more feasible by removing the necessity for levitation magnets on the train and in the track. The active components that produce the magnetic fields could be placed in the track while the train contained only less expensive passive superconductive elements that would float on the magnetic cushion, thanks to the Meissner effect.

A Short History

The phenomenon of superconductivity was first observed in 1911 by a Dutch physicist working with lead at close to absolute zero. Until mid-1986 scientists had only managed to raise the critical temperature to 23 degrees Kelvin, or -418.27 degrees farenheit, using combinations of niobium and tin or titanium. To achieve these temperatures, liquid helium was used as a coolant, a relatively costly substance. In addition, the extremely low temperatures made complex, expensive containment and support structures necessary. Practical superconductors had to be able to withstand both the terrific stress of being cooled to so low a temperature and the tremendous magnetic fields that the superconductors were often built to produce -- demanding requirements not many materials could meet. The result was that superconductivity was confined to the laboratory until only recently.

Working secretly, a West German and a Swiss researcher employed by the Swiss subsidiary of International Business Machines Corp. discovered that a compound of yttrium, barium and copper exhibited superconductivity at 35 degrees Kelvin, or -397 degrees farenheit. The 12-degree increase (Kelvin scale) over the previous record-high critical temperature was one surprising point; previous advances had been measured in fractions of degrees. More shocking was that a ceramic oxide could be superconductive at all. Furthermore, the ceramic oxide was extremely easy to make; simply mix the ingredients in the right proportion and fire them in a kiln. Its constituent elements were also relatively inexpensive and easy to obtain.

Once the IBM pair's April 1986 results were confirmed by laboratories in the United States and Japan, a research frenzy swept the globe, resulting in rapidly rising critical temperatures. Over the course of the past year important barriers have been breached. U.S. researchers reported in early 1987 that they had developed a ceramic oxide with a critical temperature of 90 to 95 degrees Kelvin, or -298 to -288 degrees farenheit, opening the way to the use of less expensive liquid nitrogen (about 25 cents a gallon as opposed to $11 for helium), which has a temperature of -320 degrees farenheit. A few months later U.S. and Japanese researchers found ceramic oxides that became superconductive in the astounding temperature range of 225 to 260 degrees Kelvin, or -45 to 9 degrees farenheit, a range within the reach of normal refrigeration equipment. The drive toward what was once a pipe dream -- room-temperature superconductors -- continued as researchers on both sides of the Pacific reported positive test results at temperatures of 65 to 75 degrees farenheit. Some U.S. researchers even claim to detect the key Meissner effect at 360 degrees Kelvin or 189 degrees farenheit.

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Better But Not Perfect

The potential benefits of superconductors are enormous, ranging from faster and smaller supercomputers to vastly more efficient electric motors and generators. But they are by no means a panacea, and in fact, present several problems of their own. Although energy loss due to electrical resistance would be eliminated, superconducting elements lose energy in other ways: by generating strong magnetic fields and large emissions of radio waves. Support and peripheral structures would also have to be redesigned to take these factors into account. Superconducting components cannot be simply substituted for existing ones because the physical and electric properties are different. Beyond these generic problems, the high-temperature ceramic oxide superconductors present a wide range of unique hurdles.

- The most fundamental question is why these materials, which are insulators at room temperature, become superconductors at all. Equally important is why they become superconducting at such high temperatures. Their discovery has forced physicists to reevaluate existing theory. At present it appears that specific defects in the crystalline structure of the ceramics (a missing atom of oxygen in the matrix, or an yttrium atom where a barium atom should be) are responsible. If scientists can determine the exact cause of superconductivity, it could lead to the development of other superconducting materials.

- A related problem is called anisotropy, where a substance conducts electricity in one direction but not perpendicular to that direction. Picture the ceramic superconductor as a stack of flat sheets. Electricity can flow along the sheets from side to side, but not through the sheets from top to bottom. The consequences for forming large objects out of the new materials are obvious.

- Also relating to their crystalline structure, the ceramic superconductors have exhibited an inability to carry high electric currents relative to their physical cross-section. It is analogous to having a frictionless water pipe that can only accommodate a trickle of water -- the lack of friction becomes pointless. Household wiring, for example, has a current density of around 120 amperes per square centimeter. The new ceramic superconductors, in contrast, show only a tenth to a hundredth of this capacity. This deficiency would affect all potential uses of the ceramics, from power transmission lines to integrated circuits. (The 5 to 12 volts common in ICs may not sound like high voltage, but remember that the "wires" on an IC can be less than one ten-thousandth of a square centimeter in size.) IBM researchers have found one way around the problem. By carefully stacking layers of the ceramic, they have achieved current densities of as much as 100,000 amperes per square centimeter. Such a technique, however, may not be applicable to forming wires and cables and may prove uneconomic for producing large objects.

- Another basic problem is production. Researchers have had little success at producing superconducting ceramics in batches of more than a pound or two. If crystal defects do turn out to be the source of superconductivity, it may prove very difficult to reproduce them consistently on a large scale. Even more frustrating, the ceramics appear to be unstable. Some researchers have reported a weakening or disappearance of superconductivity in some samples after a few days.

• Like common ceramic items, the ceramic superconductors are brittle. Instead of bending under pressure, they shatter. This presents an obvious problem in producing superconducting wire or cable and in making components that would be subjected to significant physical stress.

• Ceramic superconductors are as porous as normal ceramics; foreign substances easily invade and bind to them. Unlike normal ceramics, though, the impurities render ceramic superconductors useless. This is important in several areas, of which the most significant is integrated circuits. Superconducting ICs would combine high speed with low power consumption. Since IC elements are very small (only several hundred atoms wide in the latest generation of chips) and packed very close together, it is easy for atoms to migrate from one area to another. Preventing this migration, which is already a problem for chip engineers, would become critical if ceramic superconductors were used.

• Finally, the ceramic superconductors are every bit as hard as common ceramics. This would seem to be an advantage in some cases, but it is a drawback in others. Current methods of producing ICs rely on chemical etching processes that would not be very effective on the new ceramics. On the other hand, techniques powerful enough to handle the ceramic layers could damage the non-ceramic components. This obdurate quality also translates into high costs for machining components to final tolerances. Techniques that yield net-shape forms of the ceramics may temper this problem but are subject to other drawbacks.

One possible way to avoid these problems is to find non-ceramic high-temperature superconductors. Scientists at the Massachusetts Institute of Technology discovered in June of this year that a metal alloy of barium, copper and europium became a superconductor at 90 degrees Kelvin, or -290 degrees farenheit. The MIT group announced that the alloy could be turned into wire and ribbon with relative ease and would still retain superconductive traits. The advance may herald another fertile area for experimentation.

The Race To Commercialize

The discovery of high-temperature ceramic superconductors set off a whirlwind of activity around the globe. It quickly became clear that in this field, too, the United States and Japan would compete for global leadership. Strong challenges from China, European countries and even India cannot be ignored, however. As such, superconductors provide a good case study of the American and Japanese approaches to turning research and development into dollars and cents.

In broad terms, Japan has relied on cooperative efforts between government and industry that focus well-funded and -staffed efforts toward specific commercial applications. The government does bear a share of the research costs and supplies some staff and facilities, but its main contribution is persuading companies to pool their efforts and avoid duplication. Since the participants do much of the research in their own laboratories, the transfer of technology from government to industry is simultaneous with its development. In addition, the Japanese have made superconductors a top national priority, almost assuring sufficient funding and staffing for research. Although this effort is different from most Japanese government-industry projects in that money must also be spent on basic research to solve fundamental issues, it is certain that researchers will emphasize practical applications.

In contrast, the United States relies on the free market to provide incentives for the development of new products, on the assumption that markets are the best way to allocate capital and resources. While the government sponsors most military-related research, its involvement in commercial applications of scientific advances has been limited. Its biggest contribution is the vast amount of money provided to universities and the network of nine national laboratories.

The government has always left the commercialization of products up to individual companies -- companies that until recently could not combine their research activities. These efforts, therefore, are limited by the resources of each firm. This points to the biggest weakness of the U.S. research and development effort: insufficient attention to process and manufacturing technology. All the basic and developmental research is of little benefit if the technology cannot be applied on the factory floor.

In effect, the superconductor race will test the adaptability of both sides. Japan is skilled in the application of existing technology but weak in basic research, while American researchers exhibit the opposite traits. To win the race, both basic and applied research must be equally strong and coordinated.

From the standpoint of overall spending, the United States appears to have a lead. This is certainly true in terms of government spending. Washington targeted almost $29 million for superconductor research in the year starting October 1, 1986: $11.5 million by the Department of Defense, $10 million by the Department of Energy, $6.6 million by the National Science Foundation, and $750,000 by the National Aeronautics and Space Administration. In contrast, Tokyo neglected to budget this item for fiscal 1987; the discovery came after the budget was all but enacted. A large supplementary budget passed this September, however, has given agencies leeway to start new projects. Combined with rechanneled funds, Japanese analysts estimate that government spending in FY 1987 will be about one-fourth the U.S. amount.

The story may be different in the fiscal year starting April 1, 1988, however; estimates of total requests related to superconductors go as high as Y7 billion ($50 million at Y140=$1.00). As for private outlays, Japanese companies may be outspending their American counterparts, at least in the short term. Japanese firms have responded quickly and have shifted significant resources into this field. American companies have mounted smaller, more cautious efforts.

Japan's Entrants: The Government

Three agencies are vying for leadership of Japan's superconductor efforts: the Ministry of International Trade and Industry, the Ministry of Education and the Science and Technology Agency. The competition among these groups for funding and control is intense. But unlike other research programs, it is possible that no agency will emerge triumphant. MITI's strength has always been in the area of commercial application of technology; MOE's responsibility has been basic research; STA most often serves as an interface between public, private and academic interest groups. Each agency's traditional role forms an equally important part of a comprehensive superconductor strategy. For a change, the agencies will have to work closely to mesh their efforts --

as challenging a task for the bureaucrats as superconductivity is for scientists. The three organizations must also deal with austere spending guidelines imposed by the Finance Ministry; preliminary totals for science and education in the fiscal 1988 budget provide for inflation and just a bit more. Juggling priorities will be difficult and all three agencies expect the bulk of funding to come from private companies.

Ministry of Education - MOE's plans are simple and straightforward: to fund research on as many projects as possible at the nation's academic institutions. It remains unclear exactly how much money can be channeled in this direction, however. A shortage of researchers with the requisite background will also hamper efforts. As in the United States, superconductor research has languished in Japanese universities for the past several years. The reaction to IBM's initial discovery shows some of the institutional problems MOE faces.

The professor in charge of superconductor research at Tokyo University refused to believe the results of the IBM experiments. He did, however, show the paper to a graduate student who eventually decided to try to disprove the IBM assertions by reproducing the experiment. Much to their surprise, the ceramic oxides did indeed exhibit superconductive behavior. Had the professor not given the IBM paper to his assistant or prevented him from reconducting the experiment, Japanese researchers would have been caught completely off-guard by the rapid research that occurred in the United States. Since then, however, the universities have mobilized their resources toward answering the many questions surrounding the new materials. How the ceramics form and why they superconduct will form the basis of commercial applications and future advances.

Science and Technology Agency - Almost immediately after the discovery of high-temperature superconductors, STA launched a series of meetings and hearings around the country, both to explain the advances and to gather opinions on further development. Although these public gatherings were derided by other ministries, they fit in well with STA's broad effort to promote creativity and innovation in Japanese society. In addition, STA inaugurated an advisory group of businessmen and academics (the New Superconductivity Materials Forum) to ponder the implications of superconductors; the forum could also breed closer cooperation between the two groups.

The agency is not without research tools of its own, of course. The Physical Chemistry Research Institute is drawing up a list of project proposals for fiscal 1988 that will almost certainly include work on applications for super-fast Josephson junctions for computers. STA also promotes research through the New Technology Development Association and the Japan Research Development Corporation. While the former concentrates on helping small entrepreneurial companies get off the ground, the latter sponsors the Exploratory Research for Advanced Technology (ERATO) project. Although only three new projects were initially slated for this fiscal year (the terahertz, morphogene and molecular architecture projects), a magnetic flux quantum computer project was hastily added this fall. The six-year project will explore applications of the new materials to digital processing. STA is expected to spend at least $100 million over the next five years on various superconductor projects.

Ministry of International Trade and Industry - MITI is clearly the powerhouse when it comes to developing commercial applications. In addition to the 16 laboratories it operates under the banner of the Agency for Industrial

Science and Technology, MITI sponsors cooperative research programs with industry and is plugged into at least three advisory panels on superconductors. Of perhaps greater importance, it has ongoing projects ready to use the new superconductors. And officials are working with the Chinese government in a joint project to explore China's western regions for the rare earths that form the basis of the new ceramics. Until now, demand for these unusual elements has been limited. If the new superconductors prove practicable, however, current supplies of the components may prove inadequate.

MITI, though caught flat-footed by the IBM breakthrough, was the fastest to respond. By the time U.S. researchers broke the liquid nitrogen barrier, MITI's advisory committee was holding its first meetings. This committee included Nippon Telegraph and Telephone Corp., Matsushita Electric Industrial Co., Ltd., Hitachi, Ltd., Mitsubishi Electric Corp., Kyocera Corp. and Tokyo Electric Power Co., Inc. It should come as no surprise, then, that MITI-sanctioned joint research projects include these same companies.

AIST's efforts are centered around the Electrotechnical Laboratory at Tsukuba, near Tokyo. Projects on applying the new materials to Josephson junctions and super-powerful electromagnets are already in progress, with more planned for FY 1988. AIST also manages the Large-Scale Technologies for Basic Industries program, which will include a superconductor project next year within existing efforts to develop new materials. The National Institute for Research on Metals has developed a usable magnetic coil by embedding the new superconductors within more conventional metal alloys.

There are so many superconductor projects in progress or on the boards that MITI has no idea of their exact number or the amount of money involved. This is in part because existing projects have been broadened to encompass the new materials. The Moonlight energy conservation project and the Sunlight energy generation project are two of the more obvious areas of application. Projects aimed at developing small-scale cyclotrons for semiconductor production, large-scale particle colliders for basic research, and the commercialization of outer space are all interested in superconductors.

These direct efforts, however, pale in comparison to MITI's joint research programs with industry. MITI has already reactivated an old plan to develop a large-scale generating plant based on superconductors, attracting 11 companies from the electric power, electric machinery and wire industries. The eight-year project will cost well over Y30 billion ($214.3 million), with an initial funding level of Y1.4 billion ($10 million) in fiscal 1988. Research consortia focusing on various commercial aspects, such as wire formation, low-temperature production technology and composite technology, are likely candidates for funding. MITI continues to see its role as facilitating the conversion of basic science into commercial products. (See Appendix B for the ministry's overall strategy.) As such, it will continue to listen closely to and cooperate with industry as it pushes ahead with high-risk projects in this field.

Japan's Entrants: Industry

Not surprisingly, Japanese companies quickly realized the significance of the IBM breakthrough. Not only has industry beseiged the government with advice and volunteers for joint projects, but it has redirected major resources

to exploit these discoveries. It is probably safe to say that at least part (and sometimes a good portion) of every major Japanese corporation's research department is now working on the new materials. Although this necessarily implies a great deal of duplication and other wasted efforts, the fact that the effort is so widespread is an indication of the importance corporate Japan attaches to the subject. According to a recent government survey, industry observers expect the market for applied superconductors to grow from practically nothing today to $20 billion annually by the turn of the century. Grabbing a piece of this pie is clearly high on the business community's agenda.

Japanese firms feel they are well positioned to take advantage of the advances. Their research laboratories focus intensely on practical applications and their design and manufacturing arms work closely with the research department to bring the products quickly to market. Since process and manufacturing technologies are the key to success, the Japanese feel confident that they will be first to market. Already these firms excel in several critical areas, including wire formation techniques, ceramics, micromanufacturing and machining, semiconductor production equipment, magnetic levitation, battery technology, photovoltaics and consumer electronics.

Several firms have maintained research efforts in some fields that were abandoned by foreign competitors. NEC Corp. and Hitachi (along with MITI), for example, continued to explore Josephson junction technology after others, including IBM, had given up. Mitsubishi Electric persisted in efforts to develop a superconducting generator after Westinghouse Electric Corp. halted its experiments in 1983. Whether their past efforts will allow these firms to capitalize on the new materials, however, is unclear. But these examples are symptomatic of another Japanese strength: their willingness to take a long-term perspective and to fund lengthy efforts.

The list of companies pursuing superconductor applications is long and growing. The most interesting aspect of these activities, however, is the formation of numerous research groups with no encouragement from the government. Electric utilities and wire companies are working on wire forming technology, small optoelectronics firms have banded together for research, and even semiconductor firms are cooperating on applications. The trend could set a pattern for future endeavors, amplifying yet another Japanese strength: deep financial pockets to fund development.

In sum, it would appear that Japanese firms have redeployed their considerable forces quickly with specific targets in mind for a protracted campaign. The United States, however, is not without its own -- equally formidable -- resources.

American Companies Warm Up

While some U.S. firms are obviously excited, such as IBM, Bell Laboratories Inc. and other high technology giants, others -- including Digital Equipment Corp., American Telephone & Telegraph Co. and General Electric Co. -- are much more cautious. Although they express interest in the subject, they have not gone all-out with research support. Even when they have decided to invest, their efforts look small in comparison to Japan's: 10 to 20 researchers with moderate funding. The enthusiasm and sense of purpose are lacking. While this may indeed be the more realistic attitude, it could also unnecessarily slow development and commercialization efforts.

Nevertheless, the Japanese are awed by the fact that they are going head-to-head with the likes of IBM and Bell Labs. IBM has made key advances in the field and certainly has a trove of proprietary technology that could give it a leg up, but IBM is only one company. American firms have learned that they need to be more adept at converting laboratory advances into products, but the required changes in attitude and organizational structure have just begun. In spite of all this, the potential remains for American companies to build solid positions in their particular fields of excellence.

The U.S. venture capital industry also counts as a significant strength. Hoping to duplicate their successes in the computer and biotechnology industries, venture capitalists are hungrily eyeing the vast potential of the superconductor market. Already there are half-a-dozen start-ups using venture funds: American Superconductor Corp., Conductis, Ceramics Process Systems Corp., Monolithic Superconductors Inc. and Superconductor Technology Inc. Analysts estimate that at least $15 million will be put into superconductor enterprises this year, with even more to come. As in the case of biotechnology, these are high-risk investments. Despite a high expected rate of attrition, venture investors are excited about the possibilities.

American Universities Turn Up The Voltage

The hottest activity is clearly taking place in the academic sector. Interestingly, it appears that the number of researchers engaged in solving the problems of commercial application are increasing very rapidly. In recent years a growing number of academics have spun off successful commercial ventures based on their university research, particularly in the computer and biotechnology fields. Whether the same pattern will apply to superconductor's remains to be seen. Building computers or mixing microbes requires a much smaller initial capital investment than producing superconducting wire or magnets.

At the same time the pursuit of answers to the fundmental questions of superconductivity is attracting scientists from related and even unrelated fields. This development is encouraging because an interdisciplinary approach may bring new insights into this field. Furthermore, an understanding of the other unusual physical properties of this group of materials (they do not shine no matter how much they are polished, for example) may open the way for advances in other areas. If U.S. scientists can answer many of the basic riddles posed by the new ceramics, they may have an edge in applying the technology in the marketplace.

Washington Takes A Hand

Worried that the superconductor competition will wind up following the pattern of earlier races that resulted in Japanese dominance in videocassette recorders and computer memory chips, Washington has decided to break the tradition of government inaction on the commercialization of technology. The shift comes at an important point in the history of federal funding for research. Before the Reagan administration took over, at least half of all federal funds were for non-defense projects. This figure has fallen to around 30 percent. While companies may be able to spin off commercial applications of technology developed with DOD money, it is more likely that the technology will be so

advanced or specific that no commercial market exists. Paradoxically, the obsession with national security may have distorted the healthy structure of research and development so important to a sound economy.

Washington's decision to support superconductor commercialization efforts is, in some ways, an indictment of the free market approach as presently practiced in the United States. Pressured by the demands of stockholders and equity markets, companies have emphasized short-term profits, cannibalizing outlays for research and development or deciding against the marginal gains of using new technologies. By addressing the often high costs of commercializing a technology, the government hopes to provide counterbalancing incentives.

At a series of June hearings, Congress heard a litany of calls for action from academia and industry. The basic thrust of the statements was that while Americans continue to make discoveries, foreign competitors are making products. In response, at least two bills have been introduced that would add $80 to $100 million to current spending levels. HR 3024 divides its attention equally between applied and basic research. HR 3217 takes a longer term approach by advocating a five-year program that would increase funding to universities as well as to government agencies. Unfortunately, these bills have run afoul of efforts to reduce the federal deficit. Congressional analysts say that the chances for passage are now only about 50 percent.

The president also responded to the worried tone of the congressional hearings with his own 11-point plan (see Appendix C), which includes: amending antitrust laws to permit joint production projects; increasing protection for intellectual property; a "wise men's" advisory group; establishing superconductor units or research centers at existing U.S. agencies; and expanding activities in the field within the constraints of current budgets. The president's plan makes pointed reference to Japan by calling for "reciprocal U.S. opportunities to participate in Japanese government-sponsored research and development, including superconductivity." Equally interesting, the president presented his plan at a White House-sponsored conference open only to U.S. citizens and companies.

To date, the president's plan has yielded some concrete results. The Argonne National Laboratory has been designated as a national center for superconductor research, and laboratory officials expect this to translate into increased funding of up to $10 million. The Patent and Trademark Office has complied with Mr. Reagan's directive to expedite patent applications related to superconductivity and will grant special status to all qualifying requests.

But the government's efforts are not without controversy. Debate over whether antitrust laws should be changed is intense. Oppponents of reform point to Microelectronics and Computer Corp. and Sematech Inc., two consortia organized by U.S. electronics firms, as examples of joint research under existing laws. Proponents counter that such groups are difficult and costly to organize under current rules. There even remains resistance in the private sector to the concept that the government has a positive role to play in the commercialization of technology. The debate highlights the adjustment process the American economy is undergoing in the face of strong international competition.

Outlook

Rather than trying to predict when the first products using the new high-temperature superconductors will appear (experts estimate three to five years), an appraisal of potential bilateral superconductor issues may prove more informative. The intensity of the rivalry, which developed startlingly quickly, is apparent in the explicit reference to Japan at congressional hearings and in the president's initiative, and in Japan by the strong reaction to both these actions. Three specific areas are likely to bear the brunt of the impact:

• Intellectual property disputes - Patent and copyright disputes in the electronics and biotechnology industries are harbingers of developments in the superconductor field. IBM and an American scientist have applied for basic patents covering various types of ceramic superconductors. While the exact content of the applications has not been disclosed, Japanese companies expect them to be very broad. Since a license for these patents may be vital, firms are busy building a store of applications patents to be in a strong bargaining position.

This is particularly true of Japanese companies, where standard practice is to patent all research results whether they are used or not. In addition, Japanese law encourages a large number of patent applications by keeping application fees low and by granting very narrow or specific patents. (A patent would be required for each member of a family of products, while one patent might suffice in the United States.) The Japanese patent office has reported a torrent of superconductor-related applications over the past year and officials have informally asked the companies to slow down. Responding to the already heavy workload, the government approved legislation this year that would sharply raise application fees and broaden the scope of patents. It remains to be seen, however, if the changes will have any impact on corporate applications when they go into effect January 1, 1988.

Japanese patent activity in the United States has also been steadily rising and the superconductor revolution will undoubtedly bolster this trend. Recalling previous instances when foreign companies (notably IBM and Texas Instruments Inc.) were forced to license basic technology to Japanese competitors as a condition of doing business there (something Tokyo would be unwilling and almost unable to do today because of deregulation), some Americans are alarmed at the patent mania of the Japanese companies. Indeed, some Japanese firms admit that the feverish pace is in part designed to lay a foundation for challenging competitors' patents if the need arises.

As recent court cases in the semiconductor and computer software areas have revealed, domestic and foreign intellectual property laws need to be updated and harmonized. It has always been the case, however, that the pace of legal reform has trailed the pace of technological advancement. This is all the more reason, therefore, for Washington and Tokyo to cooperate before serious problems occur.

• National security - Of equal if not greater sensitivity, this issue has been part of the U.S. policy debate from the start. Practical, high-temperature superconductors could make magnetic rail guns (which propel non-nuclear projectiles at very high velocities) and sufficiently powerful and

radiation-proof computers practical components of the president's Strategic Defense Initiative. In addition, leadership in this field is viewed as key to economic as well as military strength because of its broad potential. Fears that Washington would pour money into military but not commercial applications of the new technology while Japan does the opposite have galvanized both the administration and Congress. In fact, the Defense Department, already concerned with dependence on foreign suppliers for critical microelectronic components, has initiated an industrial competitiveness program and will probably extend it to include superconductors. As the competition progresses, Washington will be watching closely with security in mind.

- Lack of joint international research - Compared with biotechnology and electronics, the superconductor field is relatively barren of international cooperation and joint ventures. One hopes that this is simply because not enough time has passed for joint efforts to develop. Unfortunately this may not be the case -- both the United States and Japan have held conferences on the subject that have been closed to foreigners. In addition, foreigners are barred from receiving information and other resources developed by the president's superconductivity initiative. A disconcerting tone of nationalism has crept into the competition.

Tokyo is aware of this development and has taken steps to alleviate it. MITI's superconductor program will seek out foreign researchers and foreign advisors are welcome (if they can speak Japanese). In addition, MITI hopes to sponsor international seminars on the field here as well as in Japan in an effort to increase the flow of information from Japan. Critics have disparaged these actions as too little, but they far outweigh the efforts the United States has made.

Perhaps the clearest indication of trouble is the failure to agree on a new bilateral technology exchange pact (see JEI Report No. 40B, October 23, 1987). The debate surrounding the negotiations has focused on the "closed" Japanese research system compared with the "open door" practiced by the United States. While the United States would like to place more researchers in corporate laboratories, Tokyo is hardly in a position to force private companies to cooperate. The inability to compromise reflects growing U.S. frustration at solving the Japanese puzzle.

Where does this leave both sides? It appears we are on the brink of a major revolution in electric technology but also edging closer to a new round of frictions. This situation is characteristic of bilateral competition in high technology -- a situation policymakers must learn to cope with. Failure to do so might not only damage bilateral relations but also hinder technological and economic development.

For further information, contact Jon Choy.

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The views expressed in this report are those of the author and do not necessarily represent those of the Japan Economic Institute.